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Each school year, chemistry students around the country participate in at least one lab to develop their understanding of scientific inquiry. Having spent time as a research chemist in the mining and cosmetics industries before becoming a teacher, scientific inquiry and experimental design are topics that are near and dear to my heart. Each school year, I look forward to watching my 10th-grade chemistry students struggle through a self-designed lab and (hopefully) end up successful on the other side.

Over the years, I have tried a number of inquiry projects with my students. I have had them create paper airplanes in an attempt to determine how fast they can fly, develop window cleaners to compete with commercial products, and design experiments to determine what type of light makes a solar car move the fastest (they are always amazed when black lights or single-colored lightbulbs do not move the car at all!). The problem with all of these projects? Students did not clearly understand the variables involved.

SUGAR-CUBE SCIENCE

An economical inquiry experiment for high school chemistry

As first-year chemistry students, many have never participated in a school science fair. They have memorized the steps of the "scientific method" and can recite them without any prompting from me, but when introduced to controlled, independent, and dependent variables, they hit a brick wall. That is, until last year.

I was setting up a graphing lab with sugar cubes when the idea hit me—why not have my students design a lab to determine the fastest way to make a sugar cube dissolve in water? The variables—surface area, water temperature, and agitation—are simple and easy to understand. In addition, the materials needed are inexpensive—making this lab an economical one. And as an added bonus, students would obtain background knowledge of solutions and their properties well before we discussed the topic in class.

I quickly created a lab handout (Figure 1) and grading rubric (Figure 2, p. 52) and found myself even more excited to watch my students work out this problem. I structured the lab so that students would work with only one independent variable. Other than that, they were on their own.

This article describes my experience using the sugar-cube activity in my chemistry class last year and provides suggestions for use in your classroom.

FIGURE 1

Design-a-lab guidelines.

Task

Your task is to determine the rate at which a sugar cube dissolves in water. Then, develop a method to increase this rate.

Background information

- *Solutions* are homogeneous mixtures.
- The *solute* is what gets dissolved.
- The *solvent* is what does the dissolving.

Restrictions

- You may only dissolve one sugar cube per trial.
- You may only use 30 ml of water per trial.

Instructions

- Brainstorm variables that might affect the rate sugar dissolves and decide which variable you will be testing (choose only one!).
- Develop and turn in
  - your problem;
  - hypothesis;
  - independent variable, dependent variable, and controlled variables;
  - materials;
  - safety precautions;
  - procedure;
  - data table;
  - results (i.e., a graph, a calculation of the dissolving rate in g/sec); and
  - your conclusion.

Dissolving sugar activity

Day 1

On Day 1, I introduced the problem and asked students how we could dissolve a sugar cube in the fastest way possible. An important first step was defining "dissolved" as a class. After some discussion, we agreed that a sugar cube had dissolved when no particle of the cube was visible to the eye. Students were quick to create and agree upon this definition.

Students also identified three variables: surface area, water temperature, and agitation (variables are part of a previous unit on scientific inquiry). I informed them that they would be limited to 30 ml of solvent and that they had to develop their experiments by the end of the 50-minute period.

In teams of four, students worked quickly to create a hypothesis (including the dependent and independent variables and a list of controlled variables), materials list, procedures (including safety precautions), and a blank data table.

Because of the simple nature of the problem, students determined their variables easily, but the procedure and list of materials proved difficult for them. I have found this to be a common issue in open-inquiry activities, regardless of the problem students are working on. This may be due to students' lack of inquiry-based laboratory experience.

After class on Day 1, I read through and made comments on each team's proposed experiment, then gathered their requested laboratory equipment.

Day 2

Prior to beginning their experiments on Day 2, teams had to correct any gross errors I found in their lab design before they could begin the lab. Gross errors in a self-designed lab usually occur because a team does not fully understand the previously taught concepts (e.g., identification of variables, experimental design, safety precautions, and creation of data tables). Students are also not accustomed to providing the level of detail that is necessary when developing their own procedures. It is often difficult for them to pull together a complete step-by-step set of instructions.

Once they were allowed to begin, teams had the rest of the class period to carry out their experiments and collect data. Most were able to complete their experiments by the end of class.

Day 3

Students used the final day of the activity to wrap up any loose ends in their experiments and make calculations, graphs, and conclusions. They are often fatigued at this point because the experience has been a struggle for them: They are not used to designing and troubleshooting a lab, in addition to carrying it out and documenting their results. However, students were glad to have designed and executed an entire experiment on their own.

Teacher's challenges

Having the patience to allow students to experience and overcome challenges in the lab is difficult. As educators, we want to step in and tell students what to do, or at least guide them. Refraining from giving anything more than general directions and safety precautions can be extremely difficult.

It is also a challenge to only give teams those materials they request. I recommend wearing tennis shoes on Day 2 because I frequently found myself gathering materials as students realized they needed additional equipment (and made sure they added these new materials to their original list).

Students sometimes become frustrated and impatient because of the nature of the activity. Holding your tongue—and letting students explore for themselves—is difficult, but seeing teams wrap up their labs and realize what they have accomplished is worth every minute of this struggle.

Safety and disposal

CAUTION

Safety is an important concern in all laboratory activities, but it is especially so in inquiry investigations. For this activity, students may choose to use some materials—such as glass, Bunsen burners, or hot plates—that require safety precautions and training. For this reason, teachers must check student-developed procedures for safety before allowing any group to begin work in the lab. Safety precautions should address personal protective equipment (e.g., indirectly vented chemical-splash goggles), engineering controls (e.g., eyewash station), and administrative procedures (e.g., cleaning the lab area). Students who are investigating surface area need to be aware of the hazards involved with crushing or cutting sugar cubes, depending on what instrument is used. They also need indirectly vented chemical-splash goggles, aprons, and gloves.

The materials in this lab are considered nonhazardous and can be easily disposed of according to local policy. However, if a group of students wants to change the selected solvent, be sure to look up proper disposal methods in the Materials Safety Data Sheet.

Lesson analysis

Figure 3 is an example of what students are capable of accomplishing in the beginning of the year with minimal training in creating data tables and graphs and virtually no training in designing an experiment or writing a lab report. (In my classroom, this is the first activity of the year that requires a complete lab report.) Because this is students' first attempt, I have them create a report as a team as they work through the problem, instead of after the work is completed. This

FIGURE 2

Design-a-lab rubric.

Hypothesis: Do students make specific predictions that can be measured and include an explanation? Do they list all control variables? Do they identify their independent and dependent variable?	__/5
Materials: Do students have a complete list of the materials they will need?	__/4
Procedure: Do students' procedures specify every single detail? Could an outsider be successful when following the procedure? Have students addressed safety issues, including personal protective equipment, engineering controls, and administrative procedures?	__/8
Data and results: Do students have a data table? Does the data table have appropriate headings and units for their measurements? Is the data table neat and presentable? Do students have a graph? Does the graph plot the dependent variable (*y*-axis) and independent variable (*x*-axis)? Does the graph have a title? Do the *x*- and *y*-axis labels have the appropriate units?	__/8
Conclusion: Do students evaluate their hypothesis? Do they discuss the problems they ran into? Can students make any extrapolations from their data? Have students thought about what they would do to improve their designs "next" time?	__/5
Total points	**__/30**

allows students to understand and record why each step in the process of experimental design is needed.

Last year, four of my chemistry classes completed this activity; each class was divided into groups of three or four students. Most groups chose to investigate temperature as their independent variable, and it was interesting to see how each group obtained different water temperatures. For example, some groups worked straight from the sink and others used a hot plate or a Bunsen burner to get the hot and cold water needed for their experiments (this worked out well because I was able to train the class to use the Bunsen burner earlier in the year than I normally would have).

Groups that chose agitation for their independent variable were often the most frustrated. They were

FIGURE 3

Example of student work.

Problem

How fast can sugar dissolve in water?

Hypothesis

We hypothesize that a crushed sugar cube will dissolve faster in hot water, since water molecules move faster at higher temperatures.

- *Independent variable:* temperature
- *Dependent variable:* time
- *Control:* 30 g water, crushed sugar cube

Materials

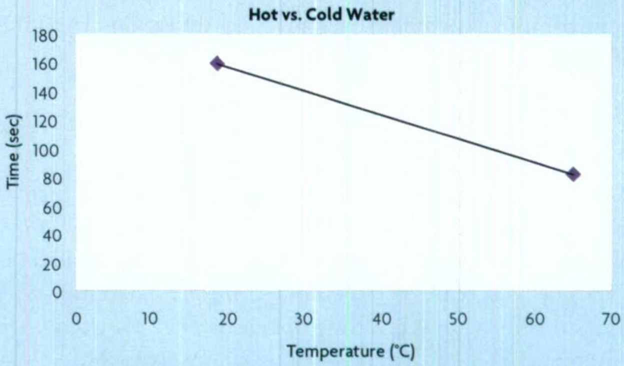
- water
- graduated cylinder
- thermometer (nonmercury)
- Bunsen burner
- two 50 ml beakers
- two 250 ml beakers
- two stopwatches
- six sugar cubes
- beaker tongs
- stirring rod
- indirectly vented chemical-splash goggles
- gloves
- aprons

Procedure

1. Using a Bunsen burner, heat 100 ml of water in a 250 ml beaker until temperature reaches 65°C (149°F).
2. Measure 100 ml of cold (18°C or 64°F) water in a 250 ml beaker.
3. Measure 30 ml of cold water in a graduated cylinder, and then pour it into a 50 ml beaker. Crush one sugar cube using a piece of notebook paper. Add the crushed sugar cube to the 50 ml beaker. Start stopwatch and stir water every 30 seconds. Record time.
4. Repeat Step 3 twice and record the time, while the water heats to 65°C.
5. When hot water has reached 65°C, use beaker tongs to remove the beaker from the Bunsen burner.
6. Pour 30 ml of hot water into a graduated cylinder. Transfer the water to a 50 ml beaker. Crush a sugar cube on a piece of notebook paper. Add crushed sugar cube to the 50 ml beaker. Start stopwatch and stir water every 30 seconds. Record time.
7. Repeat Step 6 twice and record times.

Results

Hot water (65°C)			Cold water (18°C)		
T1	T2	T3	T1	T2	T3
72 s	108 s	67 s	165 s	158 s	156 s
Average: 82 s			Average: 159 s		



Conclusion

Our hypothesis was correct. A crushed sugar cube does dissolve faster in hot water, due to the increased energy of the water molecules. We ran into one problem during our lab, however: We had to stir the crushed sugar cubes because the sugar stayed at the bottom of the beaker. Cold water did not dissolve the crushed sugar cube. Next time, we will stir more frequently—for example, every 15 seconds instead of every 30 seconds.

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surprised to find that the sugar cube did not fully dissolve in a reasonable amount of time when simply sitting in a beaker of water. These groups also had to perfect their rate of agitation. They practiced stirring beakers of water and timing how long it took to complete one stir's rotation, so that their "fast" and "slow" agitations could be quantified.

Groups that chose surface area had a somewhat difficult time figuring out how to control the surface area of the sugar cube. Some used crushed and whole sugar cubes; others cut the cube in half, in addition to crushing or not crushing the cubes. Once they perfected their procedure for crushing, these teams did just fine.

After having students design and carry out their own lab for several years now, last year was the most rewarding. I watched my students struggle and yet come out of this experience more confident than ever. My students were not only engaged, but personally involved in their work. Student comments from an assigned self-reflection are found in Figure 4.

Differentiated learning

Advanced students

Advanced students can use a computer to create a formal report as an extension of this project. This helps them review their work and write their own conclusions (as opposed to a team conclusion). Students can then take time to reflect on what they did, how they worked with others, what they learned about themselves and scientific inquiry, and how sugar goes into a solution. Students can conduct additional research on solutions and solubility, as well.

My goal for next year is to incorporate a calculation for the rate of dissolving (in grams per second) into the investigation. By tying dimensional analysis and derived units into this project, students will be able to incorporate concepts they have previously learned. I am already excited to see what next year's students will accomplish with this project!

FIGURE 4

Student reactions to the experiment.

- "I learned how to conduct my own experiment and to help my team...make a hypothesis. I enjoyed this lab because I got to help my team work through a problem and get data."
- "By completing this lab, I learned that I am capable of doing hard things—meaning I can complete hard tasks. I really enjoyed working with my team because we were determined to complete the lab, and we did!"
- "I really liked this lab because it gave us a chance to try things on our own. We went through the experience of making our own experiment and it was fun. We also used our graphing skills, which is something I needed to work on."
- "By doing this lab, I learned more about scientific method[s] and how to use [them] better. I also learned that chemists do a lot of work!"

Younger students

Some of my students used the sink to obtain different water temperatures and were able to get consistent "cold" and "hot" temperatures. For those interested in using this activity with a younger class, this would increase the activity's safety level.

Conclusion

My favorite time of year is when students get to design and carry out their own experiments to solve a problem. I have tried many different problems with my students, but this sugar-cube activity has generated the most interest in science and allowed my students to experience the true nature of science firsthand—it has also been the most economical.

When first presented with the problem of dissolving sugar, most students thought that the idea was too easy. But when we focused on the scientific principles of solute surface area, solvent temperature, and agitation, this easy concept became so much more to them. My students walked away with a greater appreciation of science and scientific inquiry. Equally important, they gained self-confidence in the laboratory and in their ability to participate in scientific inquiry. ■

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